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Experimental study on instantaneously shedding frozen water droplets from cold vertical surface by ultrasonic vibration

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A B S T R A C T

The ultrasonic vibration is introduced to remove adherent frozen water droplets from cold surface, which provides the possibilities for effective defrosting. The shedding processes of various frozen water droplets adhered to 70 mm × 70 mm cold vertical surface by 20 kHz and 60 W ultrasonic vibration were experimentally studied. It was found that the frozen water droplets instantaneously crack and shed off from the vertical surface due to the combined effects of interface transverse shear force generated by ultrasonic mechanical vibration and impact force induced by ultrasonic acoustic pressure. However, the heating effect triggered by ultrasonic vibration has limited effect on the frozen water droplets removal. Moreover, the frozen water droplets in different diameters within 2–30 mm can be successfully removed and all the frozen water droplets in different positions of 70 mm × 70 mm cold surface can be completely shed off by 20 kHz high frequency ultrasonic vibration. The results showed that the ultrasonic vibration has a very strong ability to remove the frozen water droplets, which are the parasitic substrates for frosting, from cold flat surface and thus it is a highly potential defrosting method for practical application.

1. Introduction

Frost deposition is a well-known and undesirable phenomenon in numerous fields such as air conditioning, cryogenics and aeronautics which work under low temperature conditions. The frost layer accumulated on cold surface of heat exchanger inevitably decreases the heat transfer rate of refrigerating unit due to the increase in both thermal and flow resistance. Besides, frost accreted on aircraft structures compromises aircraft performance and might cause safety problems. Therefore, great attention has been paid to searching for the effective method for preventing frost formation or removing accreted frost layer on these equipments.

Up to now, various methods concerning frost suppression and defrosting have been proposed. Thereinto, many studies have been performed to investigate the influence of surface energy on frost nucleation and growth [1–9]. In such studies, surface contact angle was changed by means of surface treatment to get the hydrophobic or hydrophilic surface. It was found that the hydrophobic/hydrophilic surface can significantly retard the initial frost nucleation. However, if the cold surface was completely covered by a thin frost layer, the surface energy no longer influences the subsequent frost growth process. Besides, numerous studies concerning the effect of various external fields on frost formation were reported [10–14]. Wang et al. [10] and Joppolo et al. [11] studied the frost formation in the presence of external electric field. They found that the frost structure subjected to external electric field is relatively skinny and fragile which could easily break up and fall off compared with that without electric field. In addition, Gou et al. [12] experimentally studied the frost formation under magnetic field. It was found that the water droplets are smaller and more homogeneous and the frost structure is easy to be removed under magnetic field. Furthermore, Cheng and Shiu [13] investigated the effect of external oscillation on the frost formation and liquid droplet solidification. It showed that the transverse oscillation of the cold plate results in a significant change in the solidification pattern of the liquid droplets. However, the frost crystals are not able to be removed from the cold plate by oscillation within the range of low frequency from 100 Hz to 200 Hz. The similar investigation was conducted by Wu and Webb [14]. Their experiment also showed that the low frequency mechanical vibration cannot successfully release the frost formed on the hydrophobic surface.

In recent years, growing attentions have been concentrated on the ultrasonic technology for frost suppression and defrosting due to the ultrasonic high frequency and energy concentration. Kazunari et al. [15] observed the frost accumulation on a rectangular aluminum alloy plate surface subjected to approximately 37 kHz ultrasonic vibration. It was found that the high frequency vibration could suppress the frost accumulation by approximately 60%. Li et al. [16] visually studied the effect of 20 kHz ultrasound on frost formation on cold flat surface in atmospheric air flow. It indicated that the coverage of initial freezing droplets is all less

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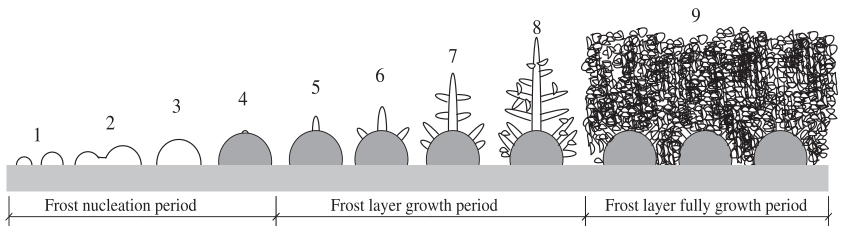

Fig. 1. Schematic representation of the entire frosting process on cold surface.

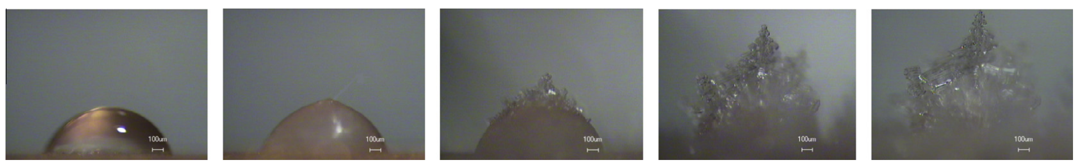

Fig. 2. Real process of frost crystal growth on the frozen water droplet surface.

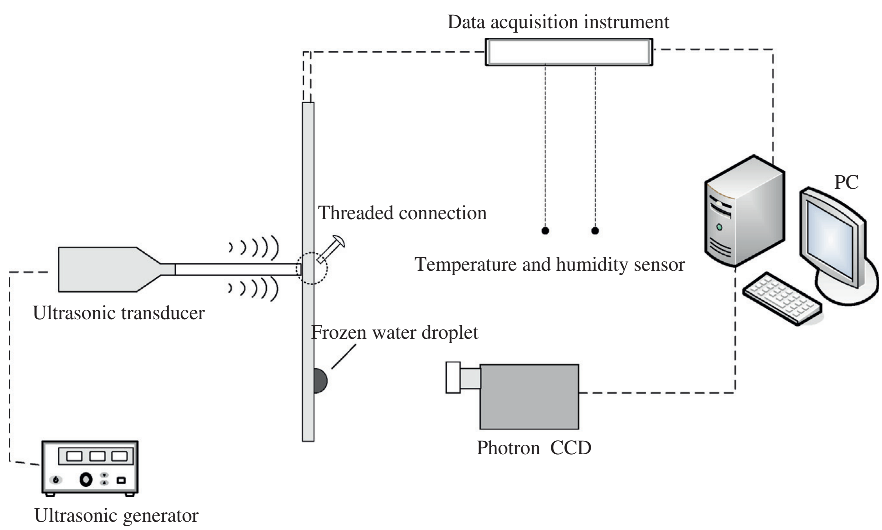

Fig. 3. Schematic diagram of experimental apparatus for frozen water droplets shedding from cold vertical surface.

than 52% with the effect of ultrasound compared with that all more than 65% without ultrasound and the rate of frost layer thickness reduction with the effect of ultrasound compared with that without ultrasound is about 75%. However, in all the tests, the ultrasonic transducer is not in contact with the flat surface which will cause significant energy decrement. Wang et al. [17] experimentally studied the possibility of frost release from a finned-tube evaporator by ultrasonic vibrations in natural convection. Their results showed that the frost crystals and frost branches on the ice layer can be fractured and removed effectively. However, the ultrasonic vibrations cannot remove the basic ice layer on the fins. In addition, Yan et al. [18] developed an ultrasonic method for defrosting and their results showed that using more ultrasonic sound sources is better than using single sound source for defrosting. Palacios and Smith [19,20] introduced an ultrasonic de-icing system for helicopter rotor blades. Their studies showed that the ultrasonic shear actuators could melt a 1.5 mm thick ice layer in a time period under 5 min at the first ultrasonic resonance frequency (130 kHz) of the system.

In summary, although a great number of investigations have been concentrated on the frost suppression and defrosting, sufficiently effective methods do not exist. Especially few effective defrosting methods have been proposed which are more attractive for the practical application. Despite quite a number of studies

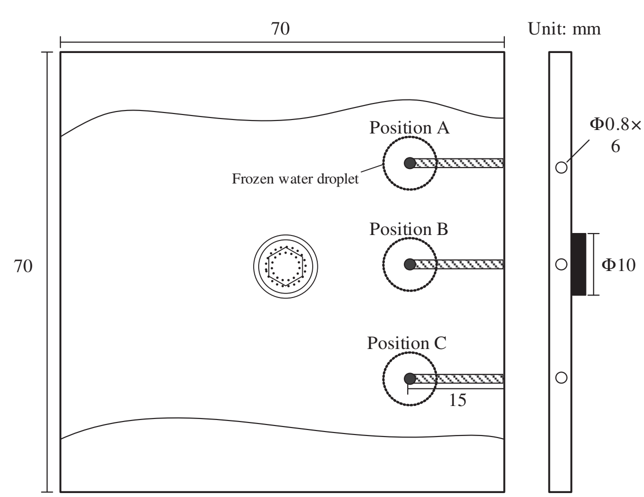

Fig. 4. Locations of screw bolt and thermocouples.

indicated that ultrasonic vibration is an effective means for frost suppression, little research has been performed on the ultrasonic defrosting owing to the mechanism of ultrasonic vibration for defrosting has not been totally revealed.